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(54) Method for freeing or preventing stuck pipe

(57) Sticking of drilling pipe can be reduced by imparting vibrational energy to it, by connecting it to a Coanda switched vortex valve (CSV), and pumping fluid, such as drilling mud or completion fluid, through the CSV and pipe, with the fluid oscillating between high and low states in the CSV to create a fluid hammer effect to impart vibration to the pipe.

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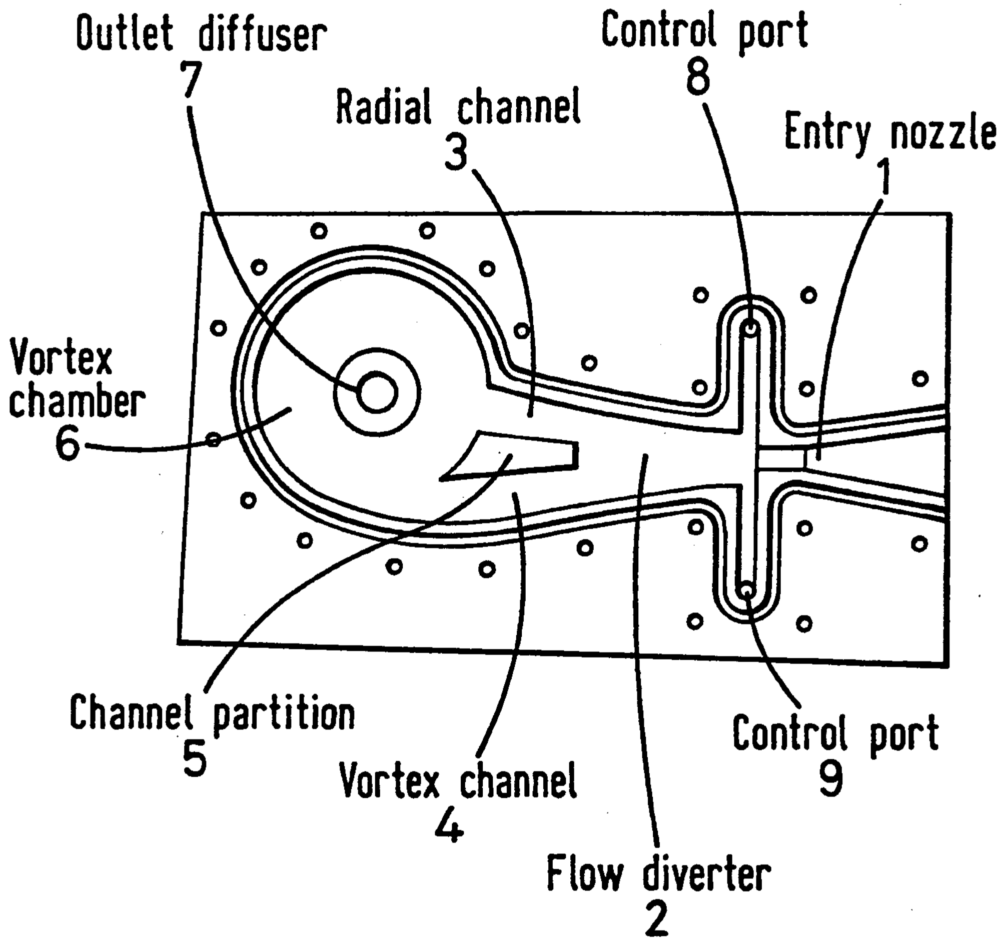

Outlet diffuser
7
Radial channel
3
Control port
8
Entry nozzle
1
Vortex
chamber
6
Channel partition
5
Vortex channel
4
Flow diverter
2
Control port
9

FIG. 1

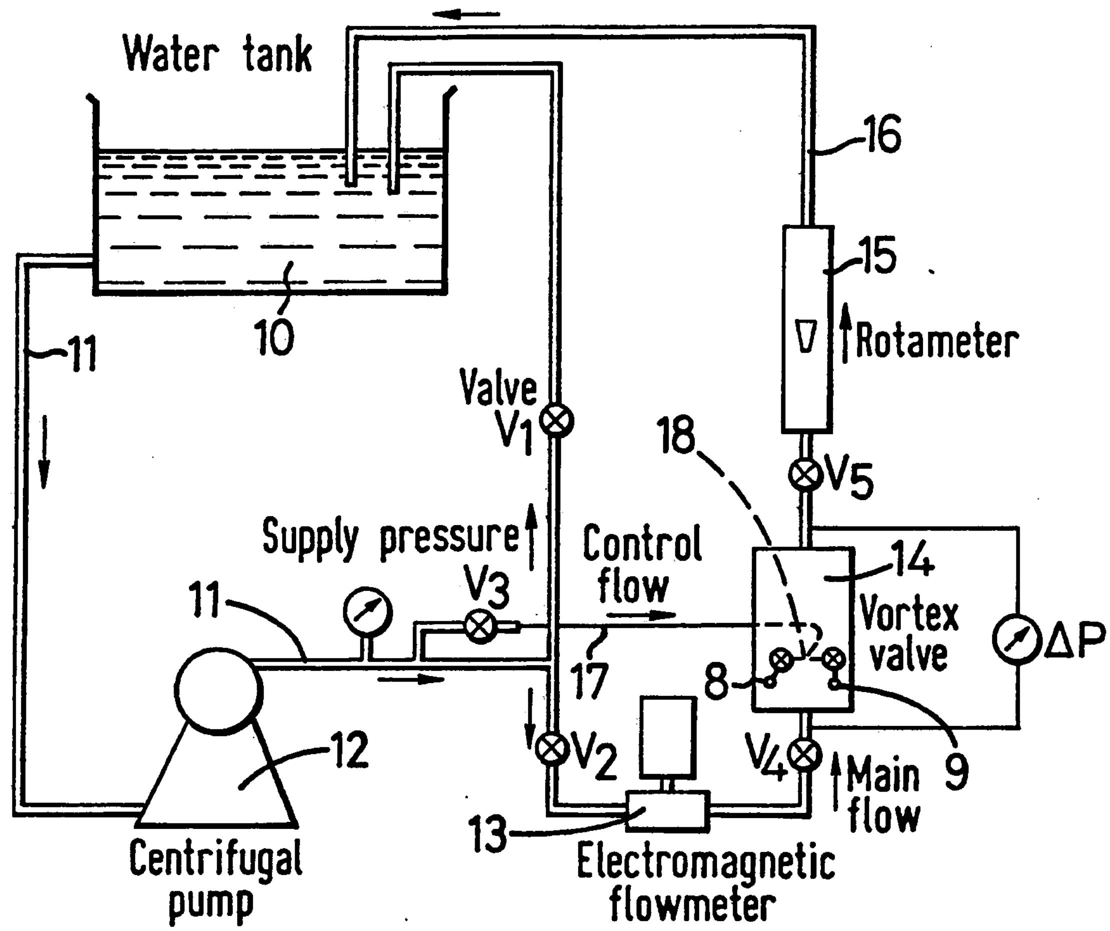
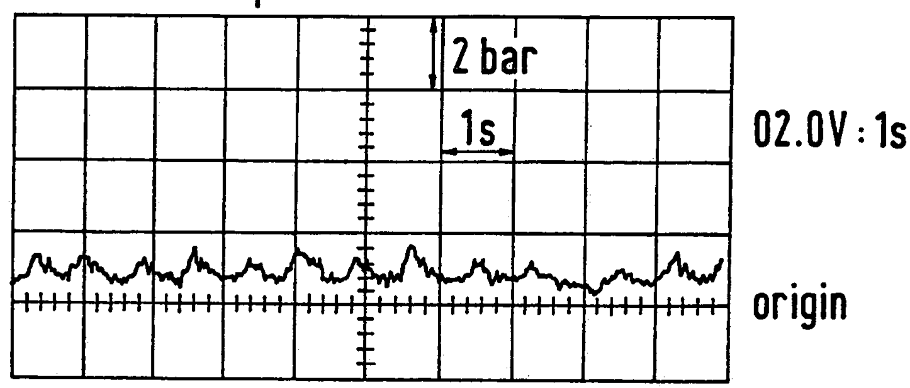

Water tank
16
15
Rotameter
10
11
Valve V1
18
V5
Supply pressure
Control flow
14
11
V3
Vortex valve
ΔP
17
8
12
V2
V4
Main flow
9
13
Electromagnetic flowmeter
Centrifugal pump

FIG. 2

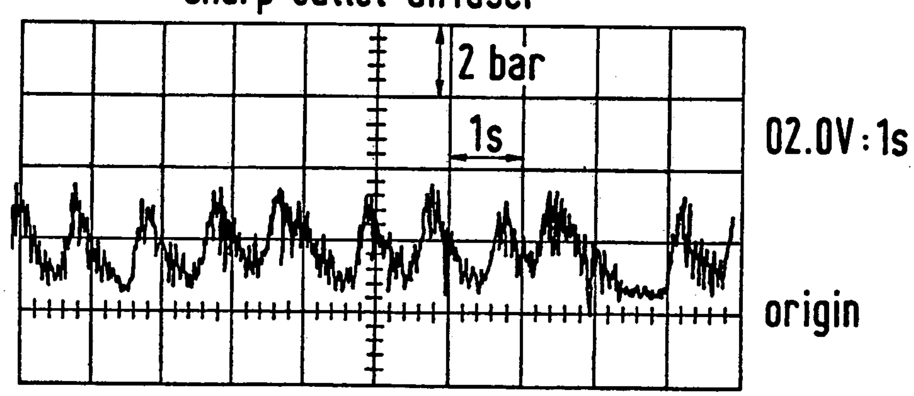
15mm channel width
sharp outlet diffuser



Differential pressure signal of oscillating flow at 50 litre / min.

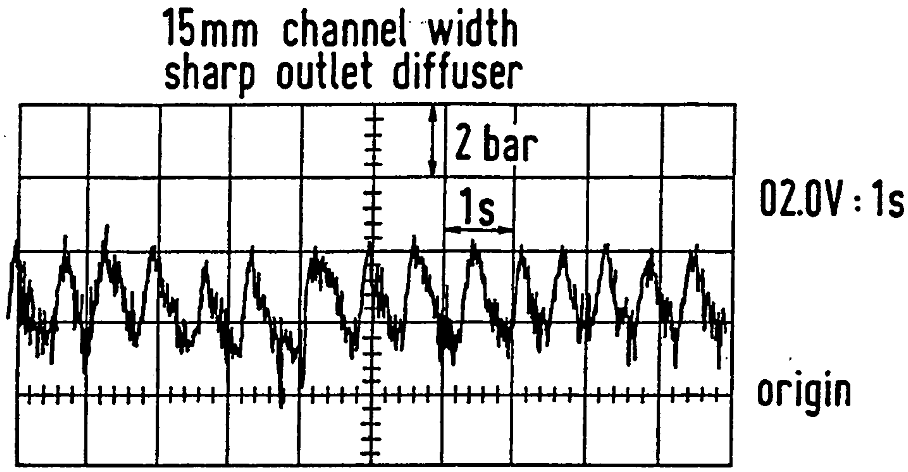
FIG. 3a

15mm channel width
sharp outlet diffuser



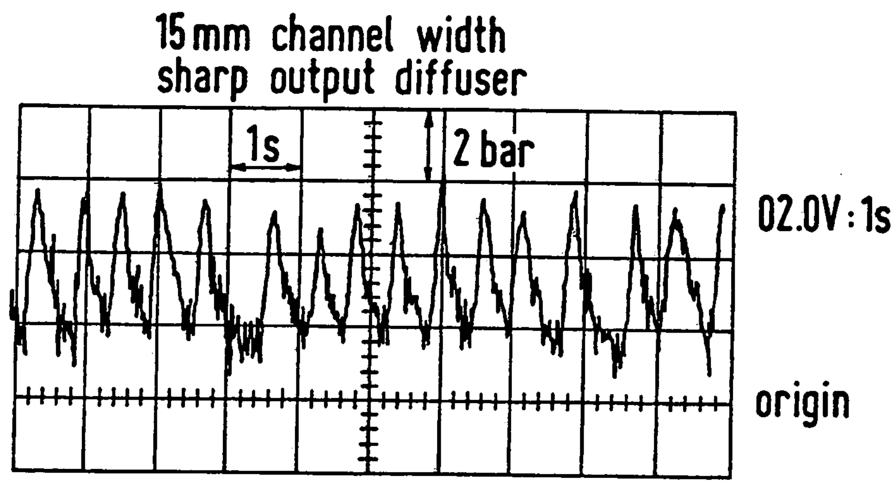
Differential pressure signal of oscillating flow at 60 litre / min.

FIG. 3b



Differential pressure signal of oscillating flow at 70 litre / min.

FIG. 3c



Differential pressure signal of oscillating flow at 80 litre / min.

FIG. 3d

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METHOD FOR FREEING OR PREVENTING STUCK PIPE

This invention relates to a method for freeing, preventing or reducing the incidence of differentially stuck pipe.

Stuck pipe may be defined as drill pipe, drill collars, drill bits, stabilisers, reamers, casing, tubing, measurement while drilling tools, logging tools, etc, having inadvertently become immovable in a wellbore. The term "stuck pipe" is used in the industry as a convenient compendious term to cover the sticking of all such equipment and is generally understood as not being restricted literally to pipes. Sticking may occur when drilling is in progress, when pipe is being run in the hole or when pipe is being hoisted.

There are numerous causes of stuck pipe. Some occur regularly, some may be peculiar to a particular area and some may be unique. Industry convention categorises the causes as either differential or mechanical sticking.

Differential sticking is believed to occur by the following mechanism. During most drilling operations, the hydrostatic pressure exerted by a drilling mud column is greater than the formation fluid pressure. In permeable formations, mud filtrate flows from the hole into the rock building up a filter cake. A pressure differential exists across the filter cake which is equal to the difference between the pressure of the mud column and the pressure of the formation.

When a pipe is central in the bore, the hydrostatic pressure due to the mud overbalance acts in all directions around it. If,

however, the pipe touches the filter cake, the mud overbalance acts to push the pipe further into the cake, thus increasing the contact area between the pipe and the cake. Filtrate is still expelled from the filter cake between the pipe and the formation, thus shrinking the cake and allowing the pipe to penetrate further into it and so increasing the contact area still more. If the pressure difference is high enough and acts over a sufficiently large area, the pipe may become stuck.

Differential sticking usually occurs when the pipe has been motionless for a period of time, eg when making a connection or during surveying. Differential sticking can be a particular problem when drilling depleted reservoirs because of the associated high overbalance.

The force required to pull differentially stuck pipe free depends, inter alia, upon the following factors:

(a) the difference in pressure between the bore hole and the formation. Any overbalance adds to side forces which may exist due to the deviation of the hole.

(b) the surface area of pipe embedded in the wall cake. The thicker the cake or the larger the pipe diameter, the greater this area is likely to be.

(c) the bond developed between the pipe and the wall cake. This is a very significant factor, being directly proportional to the sticking force. The bond can include frictional, cohesive and adhesive forces. It tends to increase with time, making it harder to pull the pipe free.

Differential sticking may be distinguished from other forms of sticking, such as mechanical sticking due, for example, to hole bridging or caving. Mud circulation is not interrupted as there is no obstruction in the hole to stop the flow, as would be the case for pipe mechanically stuck. It is not possible to move or rotate the pipe in any direction.

When a pipe sticks the driller usually tries to free it by mechanical movement, eg by pulling, jarring or, if the pipe was moving immediately prior to sticking, trying to move it in the

opposite direction. At times this fails to release the pipe and there is, of course, a limit to the force which can be applied, since too much force could fracture the pipe and make the situation worse.

We have now discovered that a Coanda switched vortex valve (CSV) may be used as a surface tool for inducing vibrations in drill pipe which can be used to shake it loose or prevent it from sticking in problem formations.

The CSV is a fluidic device, ie without moving parts. It uses a fluidic oscillator to switch fluid flow between high and low resistance states of the vortex valve. This self-induced action can produce an oscillatory fluid hammer effect in the bulk flow which is similar to the well-known phenomenon of water hammer.

The CSV comprises the combination of an inlet leading to a bistable fluid amplifier (or flow diverter) and a vortex chamber having an outlet. In addition, it has two control side ports to allow fluid to be injected into the main flow. When fluid is injected into either one of the control ports, the main flow will switch to either a high resistance state or a low resistance state depending on which control port is connected. In the high resistance state (or vortex state), the flow mainly travels through the tangential channel into the vortex chamber. Whilst in the low resistance state (or radial state), the flow mainly travels through the radial channel. By connecting both control ports together by a pipe, the main flow can be made to self-oscillate or alternate between the high and low resistance states by feedback from one control port to the other. The frequency of oscillation depends on the fluid resistance in the connecting pipe and the flow rate of the main flow (for a fixed valve geometry).

Thus according to the present invention there is provided a method for imparting vibrational energy to a drill pipe by connecting it to a CSV and pumping fluid, eg drilling mud or completion fluid, through the CSV and the pipe, the fluid oscillating between high and low states in the CSV to create a

fluid hammer effect which imparts vibration to the pipe.

The vibrational energy generated can be used in either of two modes: (1) to free a pipe from a borehole if the pipe is stuck or (2) if applied prior to sticking to prevent it from sticking in problem formations. The most likely situation for a pipe to stick is in the rest position. Therefore, while the pipe is in motion, the CSV may be kept inactive, but activated when motion stops. One benefit of the invention is that vibration can be induced in the drillstring without inducing any vibration in the surface equipment.

The method according to the present invention may have the added advantage, when compared with mechanically induced vibration, that fluctuating pressure within the annulus may reduce the differential pressure sticking the pipe. This effect will depend on the amount of damping in the system.

The pressure-flow relationship of a CSV can be expressed in terms of the pressure loss coefficient (Euler number, Eu) which is defined as the overall pressure drop across the valve divided by the dynamic pressure calculated for uniform flow in the outlet , ie,

$Eu = 2(Ps-Po)/\rho V^2$

where Ps and Po are the entry pressure and the outlet pressure respectively, ρ is the fluid density and V is the outlet velocity.

A parameter which can be used to quantify performance is the pressure drop ratio E. This is defined as the ratio of pressure drop between the two states (Eu vortex/Eu radial) when the flow is held constant.

The pressure drop ratio should be as high as feasible.

Another parameter used to characterise performance is the flow turn down ratio T which is defined as the flow ratio of the high resistance state to the low resistance state when the supply pressure is the same in both states. If the two loss coefficients are constant in the two states, the parameters T and E can be described by a simple relationship, $E = T^2$.

The invention is illustrated with reference to Figures 1, 2

and 3a-3d of the accompanying drawings wherein Fig 1 is a drawing of a CSV, Fig 2 is a diagram of a flow rig incorporating the CSV and Figs 3a-d are graphic representations of experimental results.

With reference to Fig 1, the CSV contains a tapered inlet nozzle 1 leading to a flow diverter 2 comprising a radial channel 3 and a vortex channel 4 separated by a profiled channel partition 5.

Channels 3 and 4 both lead to a vortex chamber 6 fitted with an outlet diffuser 7.

Control ports 8 and 9 are fitted across the entry to the flow diverter 2 and linked by means of a loop (not shown).

With reference to Fig 2, fluid is pumped from a tank 10 through a line 11 by a pump 12 and through an electromagnetic flowmeter 13 to the CSV 14. It is then returned to the tank 1 by way of a rotameter 15 and line 16.

For test purposes, a side stream 17 is taken from line 11 for flow control purposes and supplies fluid to loop 18 (referred to in Fig 1) and hence to control ports 8 and 9.

This enables the CSV to operate in a non-oscillating mode by connecting control fluid to either one of the control ports. Under normal operations when the oscillating mode is desired this will not be necessary.

The invention is further illustrated with reference to the following Examples.

<u>Valve Performance in Radial and Vortex Flows</u>

The performance of the rig under various geometric changes (different diffuser and channel width) are summarised in Table 1. The rig is approximately half full scale. The extreme values of E, ie, Emax and Emin, were obtained by cross-dividing the maximum and minimum values of Eu in the radial and vortex states, ie,

$$\frac{\text{Eu max (vortex state)}}{\text{Eu min (radial state)}} = \text{Emax} \quad \text{and} \quad \frac{\text{Eu min (vortex state)}}{\text{Eu max (radial state)}} = \text{Emin}$$

In general terms, the results showed that Emax was about 1.3 to 2.0 times the value of Emin for the cases studied. These results were obtained in the non-oscillating mode. The difference

between Emax and Emin was probably due to flow effects as the pressure was unlikely to be proportional to the square of velocity in highly turbulent flows such as those studied here. Similarly, Tmax was about 1.1 to 1.4 times Tmin ($E = T^2$ relationship).

When no modifications were made to the channels (Case A), the E (Emin = 3.69 and Emax = 7.38) and T (Tmin = 1.92 and Tmax = 2.72) values for the model having a sharp outlet diffuser were low. Similarly, little improvement in E and T values was obtained with the round outlet diffuser (Case C).

On the other hand, significant improvements on the E and T values were obtained when the width of the radial and vortex channels (20 mm) was careful profiled to 15 mm using fillets. The reasons for using the fillets were two fold. Firstly, by slightly changing the direction of the radial channel entry such that it had no component of tangential velocity entering the vortex chamber the formation of a strong vortex in the radial mode was avoided. Secondly, by increasing the resistance to flow in the radial and vortex channels, the flow was made less stable and hence more ready to self-oscillate. For the sharp outlet diffuser (Case D), the E (9.64, 14.41) and T(3.1, 3.8) values improved. Whilst for the round outlet diffuser (Case E), the results were even more encouraging.

With the addition of material on the expanding section of the flow diverter (Cases F & G), there was a minor degradation (10 to 20%) in the E and T values. The difference was therefore not significant.

When the width of the channels was reduced further to 10 mm (Case H), the values of E and T returned to the levels of the unmodified valve. This was later explained by flow visualisation tests which show that a considerable amount of flow travelled through both radial and vortex channels during a particular state and consequently produced no improvement in performance.

Table 1: Summary of Performance Data on Coanda Switched Vortex Value

		Radial State		Vortex State		Pressure Drop Ratio		Flow Turn Down Ratio	
Case	Valve Configuration	Eu min	Eu max	Eu min	Eu max	E min	E max	T min	T max
A	sharp outlet diffuser, open channel	2.77	4.41	16.27	20.45	3.69	7.38	1.92	2.72
B	repeat of the above	3.30	5.01	16.36	20.72	3.27	6.28	1.82	2.51
C	round outlet diffuser, open channel	3.27	4.65	16.82	21.80	3.62	6.67	1.90	2.58
D	sharp outlet diffuser, 15mm channel width	1.33	1.53	14.75	19.09	9.64	14.41	3.10	3.80
E	round outlet diffuser, 15mm channel width	0.95	1.12	17.92	20.08	16.03	21.13	4.00	4.60
F	sharp outlet diffuser, 15mm channel width, with neck restriction	1.24	1.70	15.75	19.16	9.30	15.45	3.05	3.93
G	round outlet diffuser, 15mm channel width, with neck restriction	0.99	1.24	14.30	18.64	11.53	18.83	3.40	4.34
H	sharp outlet diffuser, 10mm channel width	2.77	3.66	14.25	19.93	3.89	7.19	1.97	2.68

Frequency Measurements

For many of the flow conditions studied, the differential pressure signals (oscilloscope traces) fluctuated irregularly with respect to time. The flow showed no clear periodic oscillation. It also tended to stay in one state preferentially. For instance, it could stay in the vortex state for over 20 seconds before switching to the radial state. However, regular oscillations were obtained with both the sharp and round outlet diffusers when the channels were reduced to 15mm in width. As mentioned above, this increased the resistance in each channel which in turn reduced the stability of the flow in each flow state.

The pressure fluctuation plots (at different flow rates) for one of these conditions are shown in Figs 3a to 3d. At higher flow rates (approx 80 litre/min), the periodicity of oscillation was about 0.5 to 1 second (2 to 1 Hz). Whilst at lower flow rates (approx 50 litre/min), the periodicity was between 1 to 2 seconds (1 to 0.5 Hz). It is noted that in theses dynamic tests both the pressure drop and flow rate are fluctuating which is why the recorded pressure fluctuation ratio of around 3 is less than the pressure ratios measured in steady state at constant flowrates.

Claims:

1. A method for imparting vibrational energy to a drill pipe by connecting it to a Coanda switched vortex valve, and pumping a fluid through said valve and said pipe, the fluid oscillating between high and low states in the valve to create a fluid hammer effect which imparts vibration to the pipe.

2. A method according to claim 1 wherein said fluid is pumped through said valve when said pipe is not in motion.

3. Apparatus which comprises a drill pipe to which is connected a Coanda switched vortex valve, such that on pumping fluid through said pipe and valve a fluid hammer effect can be created.

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Patents Act 1977 **Examiner's report to the Comptroller under Section 17** **(The Search report)**	Application number GB 9323802.0
Relevant Technical Fields (i) UK Cl (Ed.M) E1F (FAW; FDD; FEH; FGL) (ii) Int Cl (Ed.5) E21B	Search Examiner D J HARRISON Date of completion of Search 18 FEBRUARY 1994
Databases (see below) (i) UK Patent Office collections of GB, EP, WO and US patent specifications. (ii) ONLINE DATABASES: WPI	Documents considered relevant following a search in respect of Claims :- 1, 2, 3

Categories of documents

X: Document indicating lack of novelty or of inventive step.

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&: Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages		Relevant to claim(s)
X	GB 2123064 A	(COMPAGNIE FRANCAISE DES PETROLES) whole document	1, 3
X	GB 2002051 A	(COMPAGNIE FRANCAISE DES PETROLES) whole document	1, 3
X	EP 0304988 A1	(SHELL INTERNATIONALE RESEARCH MAATSCHAPPIJ BV) whole document	1, 3

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